GCSS WG2

Idealized Cirrus Model Comparison Project

There is a wide range of possible environmental parameters, and combinations thereof, that may be associated with cirrus cloud occurrence, e.g.,

- relatively warm versus cold (high) cirrus,
- weak to strong forcing (generation via large scale uplift) versus dissipation,
- nighttime (infrared only) versus daytime (infrared and solar) radiative environments and the seasonal and latitudinal variations thereof,
- very stable to conditionally unstable thermal stratification,
- strongly sheared to weakly sheared versus no vertical shear of horizontal wind,
- variations of composition and concentration of the ambient aerosol population.

Based on the findings of the preliminary round of this project, as discussed at the Geesthacht Workshop in May 1999, it was decided to revise Phase I of this project. Included in the present phase are:

- A night (infrared only) simulation of a horizontally uniform, initially supersaturated and neutrally stratified (with respect to ice pseudoadiabatic processes) layer of 1-km thickness in an unsheared (no mean horizontal flow) environment subject to constant and relatively weak vertical forcing (3 cm s^{-1}).

- The baseline case should have 2 variants: a warm cirrus case and a cold cirrus case. The warm case may be regarded as corresponding to an extratropical "synoptic" cirrus situation while the cold cirrus may be interpreted as high cloud associated with the subtropical jet stream in mid-latitudes.

- Variants of the baseline warm and cold cirrus cases should be constructed to test model sensitivity to infrared radiative processes (baseline versus a no-radiation case).

- A highly useful variant of the baseline warm and cold cirrus cases would be to consider the dissipation of the cloud subsequent to elimination of the vertical forcing at some point in the simulations.

- Also highly instructive would be simulations where the ice crystal terminal velocity is set to some common fixed value.

- Simulations should be compared for a situation with a stable thermal stratification.

Specifically not considered in Phase I of the Idealized Cirrus Model Comparison Project are effects of: • solar radiation, • ambient aerosol population, • vertical wind shear.

Definition of Project – The Simulations

There are two required BASELINE simulations for the Idealized Cirrus Model Comparison Project – a warm cirrus case and a cold cirrus case. There are six additional simulations that are "highly desired" and are simple variants of these two cases (no-radiation and 2 fixed ice crystal terminal velocity options for warm and cold cases). Two other simulations are "desired" to reveal differences in model response for stable stratification.

Warm Cirrus Cases

WNir	BASELINE SIMULATION-- warm, neutral stratification, ir only
WNnr	-- warm, neutral stratification, no radiation
WNirV20	-- warm, neutral stratification, ir only, ice terminal velocity fixed at 20 cm s^{-1}
WNirV60	-- warm, neutral stratification, ir only, ice terminal velocity fixed at 60 cm s^{-1}
WSir	-- warm, stable stratification, ir only

Cold Cirrus Cases

CNir	BASELINE SIMULATION -- cold, neutral stratification, ir only
CNnr	-- cold, neutral stratification, no radiation
CNirV20	-- cold, neutral stratification, ir only, terminal velocity fixed at 20 cm s^{-1}
CNirV60	-- cold, neutral stratification, ir only, terminal velocity fixed at 60 cm s^{-1}
CSir	-- cold, stable stratification, ir only

If desired, investigators may submit results from additional simulations using different microphysical schemes, e.g., versions for something on/off. Cloud dissipation will be examined for each simulation (forcing off after 4 hours) -- see next sections.

We will also accept results from the optional simulations: WSnr, WSirV20, WSirV60, CSnr, CSirV20, and CSirV60.

Environmental Profiles – The Input Atmospheres

Four input "soundings" will be required to perform the entire set of simulations. The sounding data (ASCII) and plots thereof (postscript and pdf) are available here. The atmospheric profiles extend from the surface to a height of about 47 km. Select whatever vertical subregion that your model requires. The vertical resolution is 0.5 km in the lower troposphere, then graduates to a vertical resolution of 100 meters over a 6-km deep region containing the layer where the cloud will form (from 5 to 11 km in the warm cirrus cases and from 10 to 16 km in the cold cirrus cases). The vertical resolution then transitions to a coarser and irregular resolution at higher stratospheric levels. You should be able to construct an appropriate input data set from this, i.e., truncate and/or interpolate as required.

The specified vertical thermodynamic structure within the 6-km region of primary interest was constructed at a resolution of 0.5 km, i.e., relative humidity (ice) varies linearly with height or is constant at this scale. In the "neutral" cases (WN and CN), temperature lapse rate varies slightly at this scale within the primary cloud forming layer (1 km in depth) because the profile was constructed using the ice pseudoadiabatic lapse rate as a reference. Otherwise, lapse rate is constant at this scale.

The warm cirrus profiles are based on the U.S. Standard Spring/Fall Atmosphere at 45°N. The cold cirrus profiles are based on the U.S. Standard Summer Atmosphere at 30°N. Surface temperatures are 15°C and 31.4°C, respectively. The background tropospheric temperature lapse rate is 6.5°C km^{-1} in the former, while there is more structure in the latter. Modifications were made to ensure reasonable transitions between the regions of primary interest and the standard (background) profiles. The tropopause occurs at 11 km (-55°C) and 16 km (-75°C), respectively.

The sounding profiles include: height (km), pressure (mb), temperature (°C), and water vapor specific humidity (g kg^{-1}). The corresponding profiles of temperature lapse rate (°C km^{-1}), relative humidity with respect to a pure plane liquid water surface (RH), and relative humidity with respect to a pure plane ice surface (RHI) are also included. The Goff-Gratch standard formulas were used in all moisture calculations.

Within the region of primary interest for the warm-neutral cirrus case, temperature lapse rates are set to a value equal to the ice pseudoadiabatic lapse rate in the layer from 8 to 9 km (13 to 14 km in the cold-neutral cirrus case). For the statically stable cases, the lapse rates in these layers are set to 8°C km^{-1} in each profile.

Relative humidity with respect to ice is 100% at the base of the ice-neutral layer (8 km for the warm cases and 13 km in the cold cases) and increases linearly with height to a value of 120% at the mid-point of this layer. It remains at 120% through the upper half of the neutrally stratified layer. Linear interpolation was used to construct a transition to the background above and below these regions. Background tropospheric relative humidity (RH) is set to 40% below the high-resolution region below 5 km in the warm cirrus case

(10 km in the cold cirrus case) while a background RHI of 40% is used within the high-resolution region.

Cloud top should initially occur at a temperature of about –42°C in the warm-neutral cirrus cases and at about –61.5°C in the cold neutral cirrus cases. Cloud top temperature will be slightly warmer in the stable cases.

A "frontal" zone was added in a layer of 1 km depth located 1 km below the initially saturated "cloud-forming" layer (6-7 km in the warm cases). The purpose of this feature is to prevent instability from occurring in this region due to the vertical pattern of prescribed large-scale forcing (cooling).

Ambient Aerosol Population

Some models treat heterogeneous nucleation using parameterizations based upon other environmental parameters, i.e., a heterogeneous aerosol population is not explicitly prognosed. Some models do not include heterogeneous nucleation at all. There will be no attempt in the present project to provide commonality among the schemes used to account for heterogeneous nucleation. This is regarded as a free parameter. Some models treat homogeneous nucleation processes explicitly. Results from our preliminary simulations revealed significant differences between simulations that may have arisen largely due to differences in the assumed ambient homogeneous aerosol population. It was concluded at the Geestacht Workshop that this should not be a free parameter for the purposes here. WG2 has a second project, the Cirrus Parcel Model Comparison Project, that is examining nucleation processes in a parcel model context and with a strong focus on homogeneous nucleation. They are using similar environmental profiles (cloud temperatures) as here. To further enhance the coincidence and potential mutual benefit of these projects, it has been decided to adopt the same initial ambient aerosol population for the Idealized Cirrus Model Comparison Project as used in the CPMC Project and specified below.

Specifically, the following aerosol population is to be assumed for all models that explicitly treat homogeneous nucleation:

Aerosol composition = Sulfuric Acid

$Na = 200\ cm^{-3}$	aerosol number density
$r_g = 0.02\ \mu m$	dry mode radius
sigma = 2.3	shape factor for aerosol size distribution

From Jensen et al. (1994, J. Geophys. Res., 10421-10442),

N(r)*dr = Nt /[sqrt(2*pi) * ln sigma]* exp {-(1/2) * [(ln r - ln rg))/ln sigma]2}*d(ln r).

Solute density = $1.841\ g\ cm^{-3}$. Weast [1993], CRC Handbook of Chemistry and Physics 74th ed.). Plots of N(r) are available in the CPMC Project description on WG2 webpage.

Simulation Protocols – Further Definition of the Cases

Duration

All simulations will be run for a total of 6 hours of elapsed (simulated) time.

We will accept 4-hour simulations, but require 6-hours for at least the BASELINE cases.

Spatial Domain and Resolution

There is no mandatory requirement as regards to vertical or horizontal resolution for the test case simulations. Though recommendations are made, participants should feel free to run whatever they think is most suitable for their model and these cases. The same resolution specifications should be used for each of the test case simulations.

A vertical resolution of 500 meters is required to resolve the basic state input structure. Participating single column models (SCMs) will need to run at a vertical resolution of 500 meters or less for optimal comparability to the results of cloud resolving models (CRMs).

For the CRMs, significant differences may occur between simulations run at different resolutions, even with the same model. Given the expected convective scales in the present baseline test cases, a horizontal resolution of 100 meters or less will likely be required to reasonably resolve the motion fields within the cloud layer.

A horizontal and vertical resolution of 100 meters is recommended.

There is no mandatory spatial domain requirement for 2-D and 3-D models. A lateral (horizontal) extent on the order of 5-10 km is probably adequate.

A spatial extent of 10 km is recommended.

Vertical Motion Forcing (Generation) Implementation

Implementation of vertical motion forcing can be a significant problem for some models, especially 3-D CRMs and SCMs. In the interest of enhancing comparability, the most practical means of specifying cloud generation forcing is via a prescribed "forcing" cooling rate corresponding to the rate of adiabatic cooling that would be associated with the desired magnitude of mean vertical uplift. While there is no mean vertical advection, it does have the desired effect on cloud generation and the response of internal cloud processes, including circulation. We adopt this approach. However, the alternative direct vertical motion forcing can be applied for models where the pressure of model grid levels is prognosed, i.e., "deep" models. The rationale for this option is described below**.

A constant cooling rate will be imposed over a 3-km layer centered on the initially saturated layer, i.e., 7-10 km in the warm cases and 12-15 km in the cold cases. The cooling should decrease linearly with height to a value of zero over a 1-km deep transition layer below (i.e., from 7 to 6 km in the warm cases, and from 12 to 11 km in the cold cases), and over a 0.5-km transition layer above (i.e., from 10 to 10.5 km in the warm cases, and from 14 to 14.5 km in the cold cases).

*In order to examine cloud dissipation characteristics in the models, **Q_f** is to be suddenly and everywhere reset to zero at the 240th minute of each simulation,* i.e., there is no large-scale "cooling" during the last 2 hours of each 6-hour simulation. Thus, the last 2 hours is a cloud dissipation phase.

The "constant" value shall correspond to the adiabatic cooling rate resulting from an upward vertical motion of 3 cm s^{-1}, i.e.,

$$\mathbf{Q_f = 2.931 \times 10^{-4}\ °C\ s^{-1}} = 25.33\ °C\ day^{-1} = (g/c_p) * 0.03\ m\ s^{-1}$$

Please use this exact value to ensure comparability among our simulations. The "forcing" cooling rate, Q_f, pertains to temperature. If the thermodynamic parameter in your model is potential temperature, you must make the conversion to potential temperature cooling rate using the horizontal mean pressure at each model level, i.e., apply the potential temperature cooling rate

$$Q_f^{\theta} = Q_f \times (10^5\ Pa/p)^{0.286}$$

to all the values at each model level where p is the horizontal mean pressure at that level. Remember to do the transitions layers as described above. You will note that the lower transition zone corresponds to the "frontal" zone described in the previous section. The enhanced stability there prevents the de-stabilization of the transition region over the 4 hours that the forcing is imposed, i.e., the front disappears there while a "front" develops in the upper transition zone.

** A few models prognose pressure on model grid levels. In these cases, the imposed large-scale cooling will result in downward migration of the pressure surfaces (mass flow through fixed height grid surfaces) and compensating adiabatic warming. This is not desired. Most of the CRMs use governing equations which are not "deep", i.e., pressure is not predicted. If your model shows significant horizontally-averaged downward motion in response to the imposed cooling (will be seen even in "dry" run), you should consider the alternative of directly forcing your model via vertical motion at 3 cm s^{-1}. Please contact Dr. Starr if you will take this approach. You will have to specify an appropriately convergent large-scale horizontal wind field in the 6-7 km (11-12 km) layer in the warm (cold) cases with a balancing divergent wind field in the 10-11 km (15-16 km) layer. This approach is problematic for models with periodic boundary conditions. The large scale environment should be assumed horizontally uniform. The large-scale cooling approach is strongly recommended for everyone except those with this particular mean-vertical-motion problem.

Surface Parameters

For models with an interactive treatment of the surface and therefore requiring specification of surface parameters, it is recommended that an ocean surface be assumed such that the surface temperature remains constant over the entire 6-hour simulations. It is hoped that the lapse rate specified for the near surface layer will be sufficient to keep the layer inactive.

Initiation of Simulations

For 2-D and 3-D CRMs, it is recommended that a random number generator be used to prescribe initial potential temperature perturbations at all grid points in the initially supersaturated layer of 1-km depth where the cloud will form. This will serve to speed up the cloud generation and is common practice.

A uniform distribution of values between +0.01°C and –0.01°C is recommended.

A Gaussian distribution can also be used if a uniform distribution is not available to you. These magnitudes pertain to temperature. An adjustment to potential temperature will be needed, as with the large-scale cooling, if potential temperature is your model variable.

Ice Crystal Terminal Velocity

Because of the strong differences found in effective ice water fall speed (Vice) among models simulations and the gross sensitivity of model results to this parameter that was found in the preliminary simulation set, separate simulations of the WNir and CNir BASELINE simulations where the ice crystal terminal velocity is set to a constant fixed value for all ice crystals (and not adjusted for pressure/density) are requested. Simulations of the WNir and CNir cases where the ice crystal terminal velocity is everywhere set to 20 cm s^{-1} (WNirV20 and CNirV20) are requested. These values are toward the lower end of what was found in the bulk statistics of Vice that we collected in the preliminary round. Simulations with a fixed value of 60 cm s^{-1} are also requested (WNirV60 and CNirV60) where these represent an approximate upper bound of Vice that was found. The purpose here is to enable a better comparison of turbulence in the absence of differences of Vice. This acts to minimize the consequences of differences in ice particle size distribution, except for radiative impacts, between the models and should lead to an interesting comparison.

Output Protocols – What You Provide

The following describes the data files that will be needed for the comparison of model results. You will need to provide ftp access to these files so that we can pick them up and perform a common analysis of all the results. Just send us (David Starr with copy to Andrew Lare) an email telling us the location of the files and we'll take it from there.

Profiles of Horizontally-Averaged Parameters

The following profiles should be saved at 10 minute intervals during each simulation, i.e., 36 profiles for each parameter over each 360 minute (6 hour) simulation. Be sure to use adequate precision when doing the sums.

The time series of profiles for each parameter should be saved as a separate file. Each profile should be written in ASCII (E15.8, 2x) format as a single record (line) within the file, i.e., each file will contain 36 records or lines. PLEASE PLEASE USE THIS FORMAT AND VERIFY THAT YOU USE THE PROPER UNITS, AS REQUESTED BELOW. The file should be named using the following convention:

your_last_name.simulation_title.parameter

For example,

starr.WNir.IWC

would contain the 36 horizontally-averaged ice water content profiles for the required warm-cirrus BASELINE case (warm_neutral_infrared-only) performed by Starr.

Not all of these parameters are carried in every model. If a parameter is not carried in your model, then do not provide the corresponding output file. For example, if my model does not carry liquid water, then I do not provide a LWC file or an Nd file.

If a nested model is used (2-D or 3-D), only provide values averaged over the inner (finest resolution) grid.

Microphysical Parameters

IWC(z) profile of average Ice Water Content (g m^{-3})

LWC(z) profile of average Liquid Water Content (g m^{-3})

If you use a 2-class ice scheme, such as "pristine ice" and "snow", submit separate files for each, e.g., IWCp and IWCs. We will combine them as required.

Radiative Parameters

tau(z) profile of average cloud optical thickness at 0.5 μm wavelength.

Fup(z) profile of average upwelling infrared radiative flux (W m^{-2})
Fdn(z) profile of average downwelling infrared radiative flux (W m^{-2})

Additional Microphysical Parameters
Ni(z) profile of average number density of ice crystals (m^{-3})
Nd(z) profile of average number density of liquid water drops (m^{-3})

Again, Nip and Nis in the case of 2 classes of ice.

Dynamic and Thermodynamic Parameters
Tbar(z) profile of average potential temperature (K)
Wrms(z) level by level profile of root mean square of vertical velocity (m s^{-1})
Urms(z) level by level profile of root mean square of horizontal wind speed (m s^{-1})
TW(z) level by level profile of the average of the product of potential temperature and vertical velocity (K m s^{-1}).

No mean vertical motion is specified for any of the test case simulations, as the vertical motion forcing is accomplished via an externally specified "forcing" cooling rate. However, it is possible for a model to develop a significant mean vertical motion at one or more model levels depending on the imposed boundary conditions and other factors. All experimenters are therefore requested to also provide:

Wbar(z) profile of average vertical velocity (m s^{-1})
Ubar(z) profile of average horizontal wind speed (m s^{-1})

Please provide these latter profiles even if you believe they will always be zero.

Lastly, we will need to know the exact vertical locations of the data in the above files. You should therefore provide a file containing a single height coordinate profile (one record or line) corresponding exactly to the height (meters) coordinate profile used for the above model output profiles. Use the same ASCII format as before and name this file as:

your_last_name.simulation_title.Height

If all your simulations use the same height coordinate system, then you need only provide a single profile, i.e., your_last_name.Height. If you use a different vertical coordinate that varies in time, such as sigma coordinate, you will need to generate a Height record corresponding to each reporting time, i.e., 36 records/lines.

Probability Distributions

There is interest in the probability distribution functions (PDFs) of vertically-integrated ice water path (IWP), cloud optical depth, and the vertical velocity field. However, this is a very difficult comparison to define a priori (without first analyzing the data), e.g., what is an optimal frequency-bin scheme that can be used by all participants? Vertical velocity presents particular problems due to the likely vertical dependence of the statistics.

For the moment, the IWP (x,y) field is requested at 2, 4, and 6 hours for the 2 BASELINE simulations. Note that these data will also enable us to characterize cloud fraction, a global property, using a uniformly applied definition. If a nested model is used (2-D or 3-D), only provide values for the inner (finest resolution) grid.

One data file should be written for each of these analysis times. The data file should be written in ASCII (E15.8, 2x). For 2-D CRMs, the file should contain a single record or line containing the entire field in the horizontal (zonal) direction. For 3-D CRMs, the data file should contain a record for each grid row in the zonal (x) or meridional (y) direction with elements corresponding to locations in the alternate direction (y or x).

The files should be named as:

your_last_name.simulation_title.IWP.time_hours

For example,

starr.WNir.IWP.4

would contain the 100 column values of IWP at time equals 4 hours from my 2-D CRM (horizontal resolution of 100 meters over a 10 km domain) for the WNir BASELINE simulation.

The vertical velocity fields and cloud optical depth fields are not presently requested. Mostly, this is because I need to think more about how to handle the 3-D model fields and to get some experience with the IWP fields. However, we would be very pleased to accept vertical velocity fields (2, 4, and 6 hours) from the 2-D models for the 2 BASELINE simulations. Just use the same convention as described above for the IWP fields from the 3-D models, i.e., 2-D array of ASCII values. Name such files as:

your_last_name.simulation_title.W.time_hours

Archival of Fields

All participants are strongly encouraged to archive all their prognostic (and diagnostic) fields at 30 minute intervals during each simulation. This will facilitate rapid resolution of issues that will surely arise as the results, requested above, are compared. Significant differences between models should be anticipated and resolving why those differences occur should be very valuable to those participants. Saving a fairly complete picture of your simulations will help this to happen. It is strongly recommended that you be conservative here, i.e., the more you save the easier it will be to retrieve and analyze something.

Vertical Fall Speed

Ice crystal fall speed is of first order importance in understanding differences between simulations. It is imperative that we document what is going on in our models at a relatively succinct level. Thus, all participants in the GCSS WG2 ICMC Project are requested to do the following calculations and submit the results.

At selected times during the BASELINE simulations (minimally at 2, 4, and 6 hours), calculate the total downward ice mass flux at every grid point containing ice. If this is done on a size-bin-by-size-bin basis, you will need to accumulate the ice mass flux from all of the bins. If done on a particle-class-by-particle-class basis (pristine ice, complex ice, etc), you will have to accumulate the ice mass flux from all of the ice classes. Divide this total grid point ice mass flux value by the ice water content of that very grid point, and subtract away the vertical air velocity at that same location and time. This will produce an "effective" ice water fall speed, Vice, that will serve as the basis for the comparison.

The data set is to be sorted by ice water content (IWC) using a logarithmic binning scheme, i.e., 50 intervals of equal width in $\log_{10}(\mathrm{IWC, mg\ m^{-3}})$, plus small-value and large-value bins, as

$\log(\mathrm{IWC}) \leq -2.0$
$-2.0 < \log(\mathrm{IWC}) \leq -1.9$
$-1.9 < \log(\mathrm{IWC}) \leq -1.8$
$-1.8 < \log(\mathrm{IWC}) \leq -1.7$
…
…
$-0.1 < \log(\mathrm{IWC}) \leq 0.0$
$0.0 < \log(\mathrm{IWC}) \leq 0.1$
$0.1 < \log(\mathrm{IWC}) \leq 0.2$
…
…
$2.8 < \log(\mathrm{IWC}) \leq 2.9$
$2.9 < \log(\mathrm{IWC}) \leq 3.0$
$3.0 < \log(\mathrm{IWC})$

There are a total of 51 bins.

What is then desired is a calculation of the mean value and standard deviation for Vice in each bin along with determination of the minimum and maximum values. However, this requires that each bin have an adequate population of values. Moreover, we want to be able to combine the samples from different times while retaining the time-dependent aspects of the statistics. To avoid building (saving and updating) a rather large database of all the sorted IWC values in all the bins prior to evaluating the statistics, it is requested that the analysis-and-sort at each time be used to update accumulated values for:

number of samples in the bin
sum of all values in the bin
sum of squares of all values in the bin

as well as the maximum and minimum "encountered-to-date" values. These five parameters will define the desired statistics for each bin without having to build and retain an excessively large database. Thus, do not submit the means and standard deviations, but rather the numbers, sums and squared sums.

The files should be named as:

your_last_name.simulation_title.Vice.time_hours

For example,

starr.WNir.Vice.4

would contain a matrix of the statistical parameters at the 4 hour mark of the WNir BASELINE simulation. The parameters are to be arranged as 5 columns (for each log(IWC) bin: number of Vice values, sum of all Vice values, sum of square of all Vice values, maximum value of Vice, minimum value of Vice) and 51 columns representing the IWC bins from small to large.